Improving Laser Beam Performance and Operational Reliability

THE National Ignition Facility (NIF) houses the world's most energetic laser built to study the fusion processes that occur inside stars, supernovae, and exploding nuclear weapons. It was designed to create the conditions required to ignite controlled fusion reactions that could someday serve as an energy source.

To enhance the performance and operability of this and other laser facilities as well as meet the requirements of future laser-driven fusion power plants, a team led by Livermore's John Heebner in collaboration with Meadowlark Optics in Colorado developed the LEOPARD (laser energy optimization by precision adjustments to the radiant distribution) system. The system is now operational on NIF, and the team has won an R&D 100 Award for the new technology.

LEOPARD precisely adjusts a laser beam's radiant distribution or intensity profile, enabling the correction of residual imperfections in a beam. The system also protects fragile regions containing flaws on downstream optics by locally shadowing the beam where it overlaps the flaws. This technique allows the maximum amount of energy to be extracted from the laser amplifiers while preserving a high degree of reliability among the optical components.

Hybrid Design Provides Unique Capability

At the heart of LEOPARD is a hybrid design consisting of two liquid-crystal-based spatial light modulators. The first modulator is of the type found in conventional liquid crystal display (LCD) projectors; that is, it is pixelated and can be electrically controlled or addressed with a digital image. The second modulator is unconventional in that it is nonpixelated, analog, and optically addressed by the images projected from the first. Both contain twisted nematic liquid crystal molecules used in most LCD TVs, monitors, and projectors.

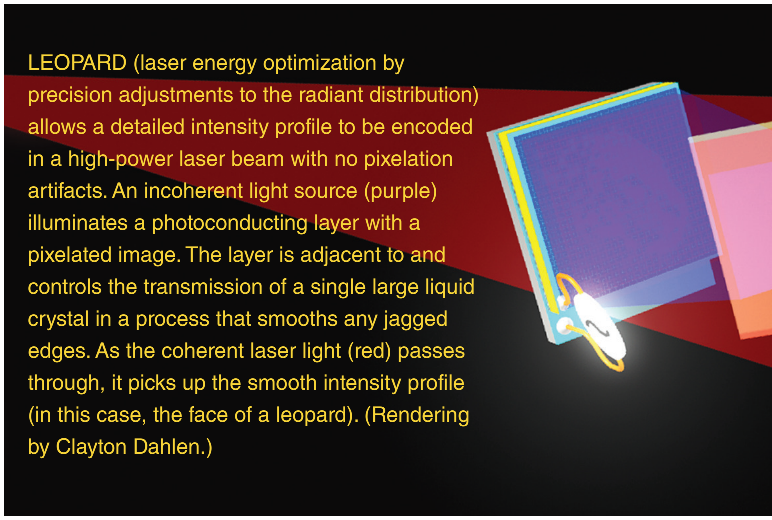
To preserve the existing NIF laser beam quality while adding the capability to create smooth beam shapes, the team customized the second modulator in the hybrid design. This modulator, called an optically addressable light valve (OALV), contains a liquid crystal cell, but unlike a conventional, pixelated liquid crystal cell matrix, it consists of only a single, giant pixel.

The orientation of the liquid crystal molecules is controlled with a voltage applied across transparent electrode layers surrounding the liquid crystal layer. The LEOPARD design also incorporates a photoconductor layer adjacent to and in series with the liquid crystal layer. As a result, the local voltage across a patch of the liquid crystal layer can be controlled by the local brightness of light illuminating the photoconductor. This control can happen only if the photon energy of the illuminating light is higher than the bandgap energy of the photoconductor such that it can be absorbed, turning the insulator into a conductor. The process short-circuits the photoconductor layer, allowing the voltage to be applied locally to the liquid crystal layer and opening a local transmission window for the laser beam. This mechanism enables a weak, incoherent image pattern consisting of bright and dark features to control the pattern of transmission for a much higher energy coherent laser beam.

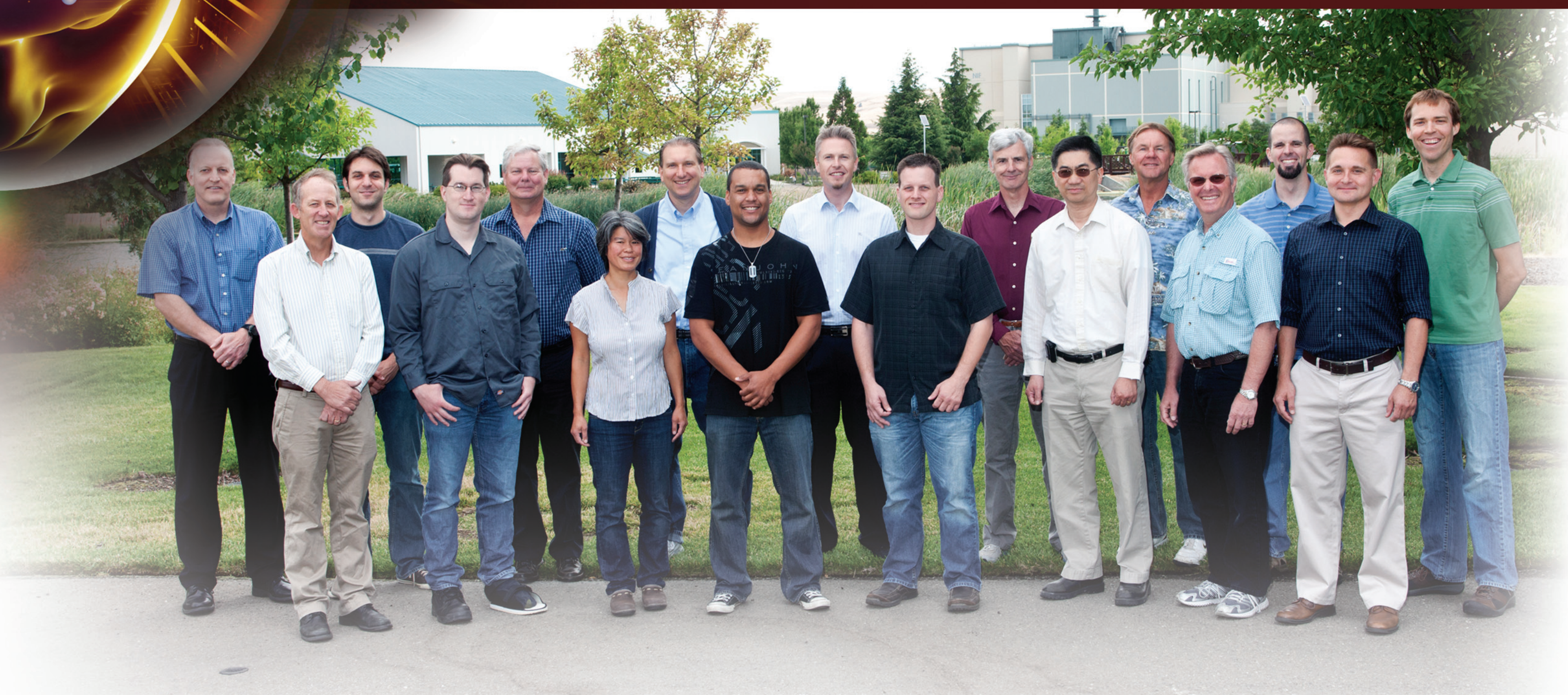
Because OALV is unpixelated and analog, it is well suited for creating ultrasmooth laser beams with arbitrary shapes. For the NIF application, it also had to satisfy a set of stringent requirements typically not possible with conventional, pixelated liquid crystal modulators. These requirements included achieving a more than 90-percent transmission, imparting minimal wavefront distortions, and avoiding the creation of temporal interference patterns (also known as amplitude modulation), all in a plug-and-play module.

LEOPARD's Spots

The LEOPARD capability added to NIF's 192-beam laser system enables operators to introduce obscurations, or "blockers,"

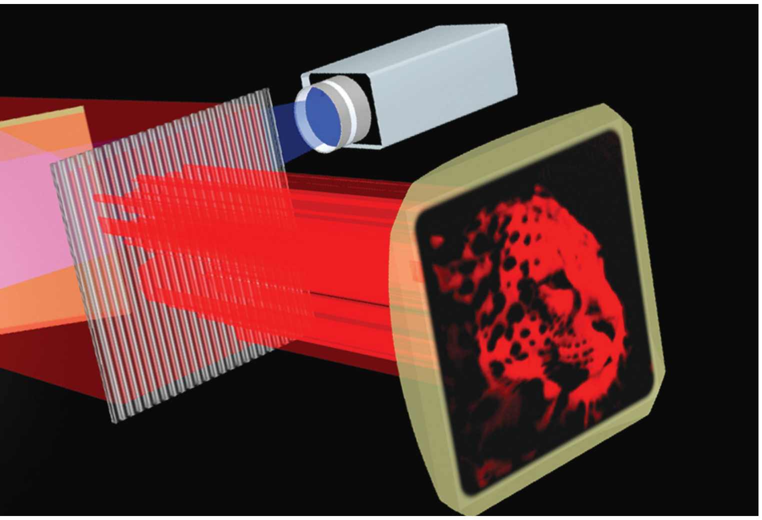


LEOPARD (laser energy optimization by precision adjustments to the radiant distribution) allows a detailed intensity profile to be encoded in a high-power laser beam with no pixelation artifacts. An incoherent light source (purple) illuminates a photoconducting layer with a pixelated image. The layer is adjacent to and controls the transmission of a single large liquid crystal in a process that smooths any jagged edges. As the coherent laser light (red) passes through, it picks up the smooth intensity profile (in this case, the face of a leopard). (Rendering by Clayton Dahlen.)



Livermore development team for LEOPARD: (from left) Michael Borden, Phil Miller, Marcus Monticelli, Matt Rever, Mark Franks, Nan Wong, Michael Taranowski, Eric Imhoff, Gordon Brunton, Jeff Jarboe, Steve Hunter, Eddy Tse, Kim Christensen, Jeff Wilburn, Edward Von Marley, John Heebner, and Kevin Williams. (Not shown: Jean-Michel Di Nicola, Sham Dixit, Lynn Seppala, Mike Scanlan, Tracy Budge, Larry Smith, and Abdul Awwal.)

upstream, which shadow flaws downstream in the final optics. In preparation for each high-energy firing sequence, the laser beam is first imaged at low power and overlaid with inspection images of the final optics. An automated control system then decides whether the beam fluence needs to be reduced in areas containing flaws that could grow with repeated laser shots. Temporarily shadowing a flaw buys time, enabling the continued operation of NIF until the optic can be removed, refurbished, and reinstalled.



"The LEOPARD system was designed to dramatically improve the performance and operational reliability of laser systems," says Heebner. "The system saves NIF an estimated $5 million annually in direct refurbishing costs and eliminates operational delays that might be incurred by the refurbishing cycle. Many other high-energy lasers worldwide could be optimized for increased extractable energy and achieve greater operational lifetimes using LEOPARD."

NIF is designed to produce the first demonstration of controlled inertial-confinement fusion where the energy released is greater than the laser energy input. For NIF's 192 beams (48 quads) to be operated at optimum performance and with high reliability, a system of 48 precisely programmable beam shapes is essential. The LEOPARD system meets this need and sets a new defining standard for precise control of the most energetic laser system ever constructed.

—Cindy Cassady

Key Words: fusion energy, laser energy optimization by precision adjustments to the radiant distribution (LEOPARD), liquid crystal modulator, optically addressable light valve (OALV), R&D 100 Award, shadow blocker.

For further information contact John Heebner (925) 422-5474 (heebner1@llnl.gov).